SUPPLEMENTARY MATERIALS TO ACCOMPANY

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Attentional capture by threat-signalling stimuli persists even when entirely counterproductive

Samantha Mikhael[1]*, Poppy Watson[1]*, Brian A. Anderson[2], & Mike E. Le Pelley[1]

1. School of Psychology, UNSW Sydney
2. Department of Psychology, Texas A&M University

* These authors contributed equally to this work

Corresponding author:
Prof Mike Le Pelley
School of Psychology
UNSW Sydney
Sydney
NSW 2052
Australia

This document describes analyses of gaze dwell time on CS+ and CS– distractor stimuli, and latencies of first saccades towards distractors and targets, in Experiments 1 and 2.

Experiment 1

Saccade Latency

We analysed the latency of participants' first saccades, as a function of the direction of those saccades (towards the diamond target versus towards the colour-singleton distractor) and the type of distractor present in the search display. Saccade latency was defined as the period between onset of the search display and the first saccadic eye-movement, with saccades identified using a velocity-threshold identification algorithm (Salvucci & Goldberg, 2000). Specifically, the first saccade was defined as the first period over which eye-movement velocity exceeded 40° visual angle per second for at least 20 ms, and for which the end-point lay more than 2.55° (100 pixels) from the fixation point at the centre of the screen. Following our previous protocols (Le Pelley et al., 2019; Pearson et al., 2016; Watson, Pearson & Le Pelley, 2020), trials were excluded from saccade analysis if the participant made an anticipatory saccade (saccade latency below 80 ms), if no gaze was recorded within 100 pixels of the central fixation point in the first 80 ms of the trial, or if no saccade was detected. These criteria led to exclusion of a further 12.5% of trials (in addition to trials excluded as described in the "Data Pre-Processing" section of the main text). As in our previous work, saccades were defined as going towards the target or the colour-singleton distractor if the saccade vector had an angular deviation of less than 30° clockwise or anti-clockwise from the respective stimulus in the display.

Saccades to the Target

Figure S1a shows latency of first saccades that went towards the diamond target. These data were analysed using ANOVA with a between-subjects factor of information group (Full-Info vs Control), and within-subjects factors of distractor (i.e., whether the search display contained a CS+ or CS– distractor) and phase (BeforeInfo vs AfterInfo). This revealed a main effect of distractor, with slower saccades to the target when the display contained a CS+ distractor versus CS–, $F(1,58) = 13.0$, $p < .001$, $\eta_p^2 = .183$. There were also significant interactions between information group and distractor, between information group and phase, and between distractor and phase, all $F(1,58) \geq 6.90$, $p \leq .011$, $\eta_p^2 \geq .106$. Given our primary focus on the effect of distractors on performance, pairwise tests (using a Bonferroni-corrected critical *p*-value of .0125) were used to examine the effect of distractor as a function of information group and phase. This revealed a significant effect of distractor for the Full-Info group in the AfterInfo phase, $t(29) = 4.11$, $p < .001$, $d_z = 0.75$, with slower saccades to the target when the display contained a CS+ distractor versus CS–; all other contrasts were nonsignificant, all $t(29) \leq 1.43$, $p \geq .163$, $d_z \leq 0.26$.

Saccades to the Distractor

Figure S1b shows latency of first saccades that went towards the colour-singleton distractor; two participants (both in group Full-Info) registered no valid saccades towards one of the classes of distractor during one of the phases of the procedure and hence were excluded from this analysis. ANOVA with factors of information group (Full-Info vs Control), distractor (CS+ vs CS–) and phase (BeforeInfo vs AfterInfo) revealed no significant main effects or interactions, all $F(1,56) \leq 3.01$, $p \geq .088$, $\eta_p^2 \leq .051$.

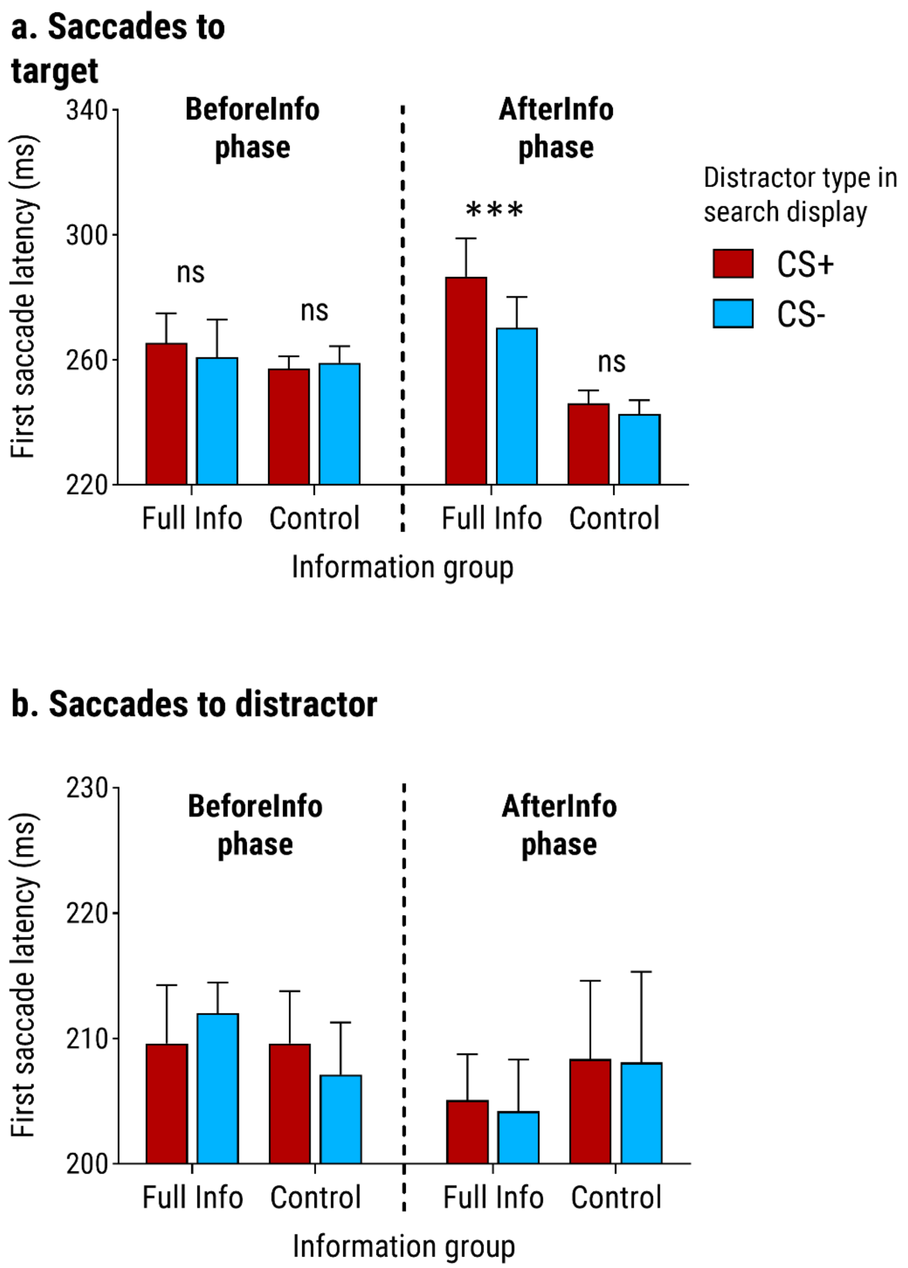

Figure S1. Mean latency of first saccades to **(a)** the diamond target, and **(b)** the coloured distractor in Experiment 1, as a function of whether the display contained a CS+ or CS– distractor. Data are shown separately for the BeforeInfo phase (prior to any instructions about the relationship between the CS+ and noise) and the AfterInfo phase (after the Full-Info group had been instructed that looking at the CS+ caused the noise; the control group were never informed of this relationship). Error bars show within-subjects 95% confidence interval (Morey, 2008). *** p < .001; *ns* non-significant.

Gaze Dwell Time

For the subset of trials on which participants looked at the coloured distractor stimulus (CS+ or CS–), we calculated the mean duration for which gaze fell within the region of interest of radius 2.55° visual angle (100 pixels) centred on this distractor. Figure S2 shows the resulting mean gaze dwell time on distractors across phases of Experiment 1 (two participants, both in group Full-Info, did not look at the CS– distractor on any trial of one of the phases; hence these participants were excluded from analyses of dwell time).

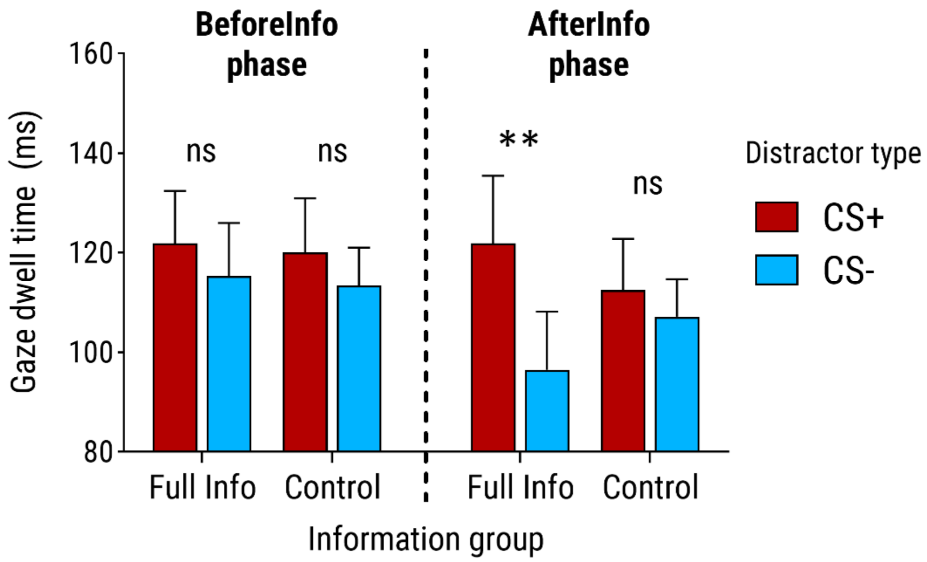

Figure S2. Mean duration of gaze on colour-singleton distractors in Experiment 1, on trials in which participants looked at the distractor, for each distractor condition (CS+ and CS–). Data are shown separately for the BeforeInfo phase (prior to any instructions about the relationship between the CS+ and noise) and the AfterInfo phase (after the full-info group had been instructed that looking at the CS+ caused the noise; the control group were never informed of this relationship). Error bars show within-subjects 95% confidence interval (Morey, 2008). ** $p < .01$; *ns* non-significant.

These data were analysed using ANOVA with a between-subjects factor of information group (Full-Info vs Control), and within-subjects factors of distractor (CS+ vs CS-) and phase (BeforeInfo vs AfterInfo). This analysis revealed a significant main effect of distractor,

$F(1,56) = 13.2$, $p < .001$, $\eta_p^2 = .191$, with gaze dwelling for longer on the CS+ than the CS–. No other main effects or interactions were significant, largest $F(1,56) = 3.57$, corresponding $p = .064$.

Even though the three-way interaction in the omnibus ANOVA was non-significant ($p = .146$), we used pairwise tests to examine the effect of distractor as a function of information group and phase, against a Bonferroni-corrected significance threshold of $p = .0125$. This revealed a significant effect of distractor for the Full-Info group in the AfterInfo phase, $t(27) = 2.88$, $p = .008$, $d_z = 0.54$, with greater dwell time on the CS+ distractor than the CS– distractor; all other contrasts were nonsignificant, all $t(27) \leq 1.14$, $p \geq .263$, $d_z \leq 0.21$.

The above analyses demonstrate that gaze dwelled for significantly longer on the CS+ than the CS–, particularly in the Full-Info group during the AfterInfo phase. This difference could reflect a difference in attentional disengagement, wherein a threat-related distractor holds attention for longer than a neutral distractor (cf. Watson, Pearson, Theeuwes, et al., 2020). An alternative possibility is that the difference reflects a startle response to the delivery of the aversive noise that occurred on 50% of the trials on which participants looked at the CS+ (with the noise delivered immediately when gaze was first detected on the CS+). That is, the noise may have caused 'behavioural freezing' (Clarke et al., 2013), thus delaying disengagement from the CS+ distractor. To investigate this issue, we compared dwell time on the CS+ on trials on which the noise was delivered, versus trials on which participants looked at the CS+ but the noise did not occur: see Figure S3. If the difference in dwell time to CS+ versus CS– observed in Figure S2 reflected a change in the attention-holding properties of the CS+ itself, then dwell time on noise and no-noise trials with the CS+ should be similar; if instead the 'CS+ vs CS–' difference reflects an unconditioned effect of the noise, then we should see greater dwell time on noise trials than no-noise trials. The empirical data in Figure S3 support the latter pattern: ANOVA with factors of information group, phase, and trial outcome (noise versus no-noise) revealed only a main effect of trial outcome, $F(1,57) = 17.5$, $p < .001$, $\eta_p^2 = .23$, with longer dwell on the CS+ on trials on which the noise was delivered than when it was not; all other $F(1,57) \leq 2.75$, $p \geq .102$.

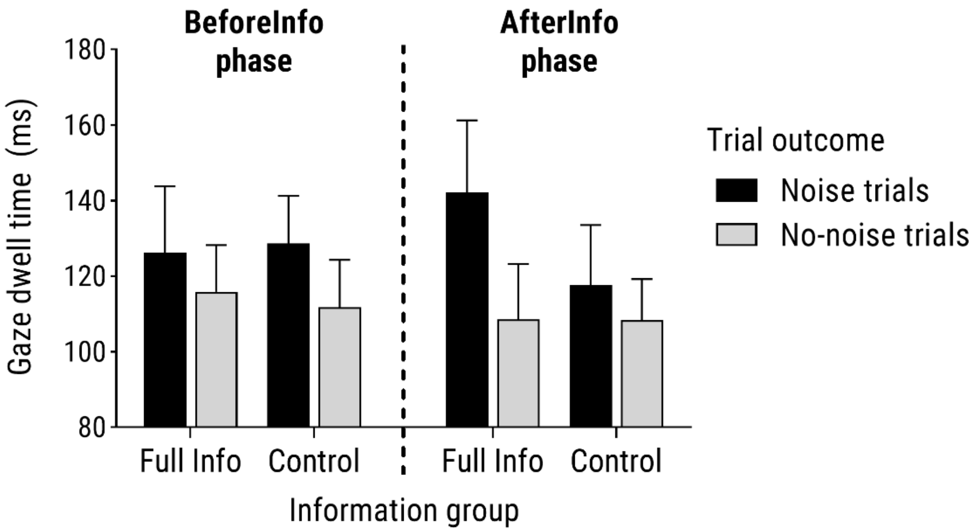

Figure S3. Mean duration of gaze on the CS+ distractor in Experiment 1, on trials in which participants looked at that distractor, as a function of whether the aversive white noise occurred (noise trials) or did not occur (no-noise trials) when participants looked at the CS+. Error bars show within-subjects 95% confidence interval (Morey, 2008).

It seems likely that this unconditioned effect of the noise on attentional orienting was the source of the overall difference in dwell time between CS+ and CS– trials for the Full-Info group during the AfterInfo phase (see Figure S2). These participants became more likely to look at the CS+ than those in the Control group (see Figure 2 in the main text), and hence would have experienced more trials on which looking at the CS+ was followed by noise; whereas looking at the CS– was never followed by noise. If (as indicated above) the noise caused behavioural freezing, this would explain why there was a pronounced difference in dwell time on CS+ versus CS– trials in this particular condition. Notably, for the Full-Info group in the AfterInfo phase, comparing dwell time on CS– trials (*M* = 96.0 ms) with dwell time on CS+ trials *on which no noise was delivered* (*M* = 108.6 ms) yielded a non-significant difference, $t(28) = 1.25$, $p = .222$, $d_z = 0.23$. That is, when any 'external' effect of the noise on gaze was removed, there was no longer evidence of significantly greater dwell time on the CS+ than the CS–.

We postpone further discussion of the findings relating to saccade latency and dwell time until after reporting analyses of the corresponding data from Experiment 2.

Experiment 2

Saccade Latency

Analysis of the latency of first saccades, as a function of the direction of those saccades, used the same protocol as for Experiment 1. Exclusion of trials with anticipatory saccades, no gaze recorded within 100 pixels of the central fixation point in the first 80 ms of the trial, or with no saccades detected, led to removal of a further 8.9% of trials (in addition to trials excluded as described in the "Data Pre-Processing" section of the main text).

Saccades to the Target

Figure S4a shows latency of first saccades that went towards the diamond target. These data were analysed using repeated measures ANOVA with factors of distractor (i.e., whether the search display contained a CS+ or CS– distractor) and phase (Unrewarded vs Rewarded). This revealed a main effect of distractor, $F(1,26) = 22.5$, $p < .001$, $\eta_p^2 = .464$, with slower saccades to the target when the display contained a CS+ distractor versus CS–. There was also a significant main effect of phase, with slower saccades in the (first) Unrewarded phase than the (second) Rewarded phase, $F(1,26) = 84.4$, $p < .001$, $\eta_p^2 = .765$. The interaction was not significant, $F(1,26) = 2.30$, $p = .142$, $\eta_p^2 = .081$. Pairwise tests (using a Bonferroni-corrected critical p-value of .025) were used to examine the effect of distractor in each phase, and revealed a significant effect of distractor in both the Unrewarded phase, $t(26) = 4.04$, $p < .001$, $d_z = 0.78$, and the Rewarded phase, $t(26) = 3.78$, $p < .001$, $d_z = 0.73$.

Saccades to the Distractor

Figure S4b shows latency of first saccades that went towards the coloured distractor. ANOVA with factors of distractor (CS+ vs CS–) and phase (Unrewarded vs Rewarded) revealed no significant main effects or interactions, all $F(1,26) \leq 2.23$, $p \geq .147$, $\eta_p^2 \leq .079$.

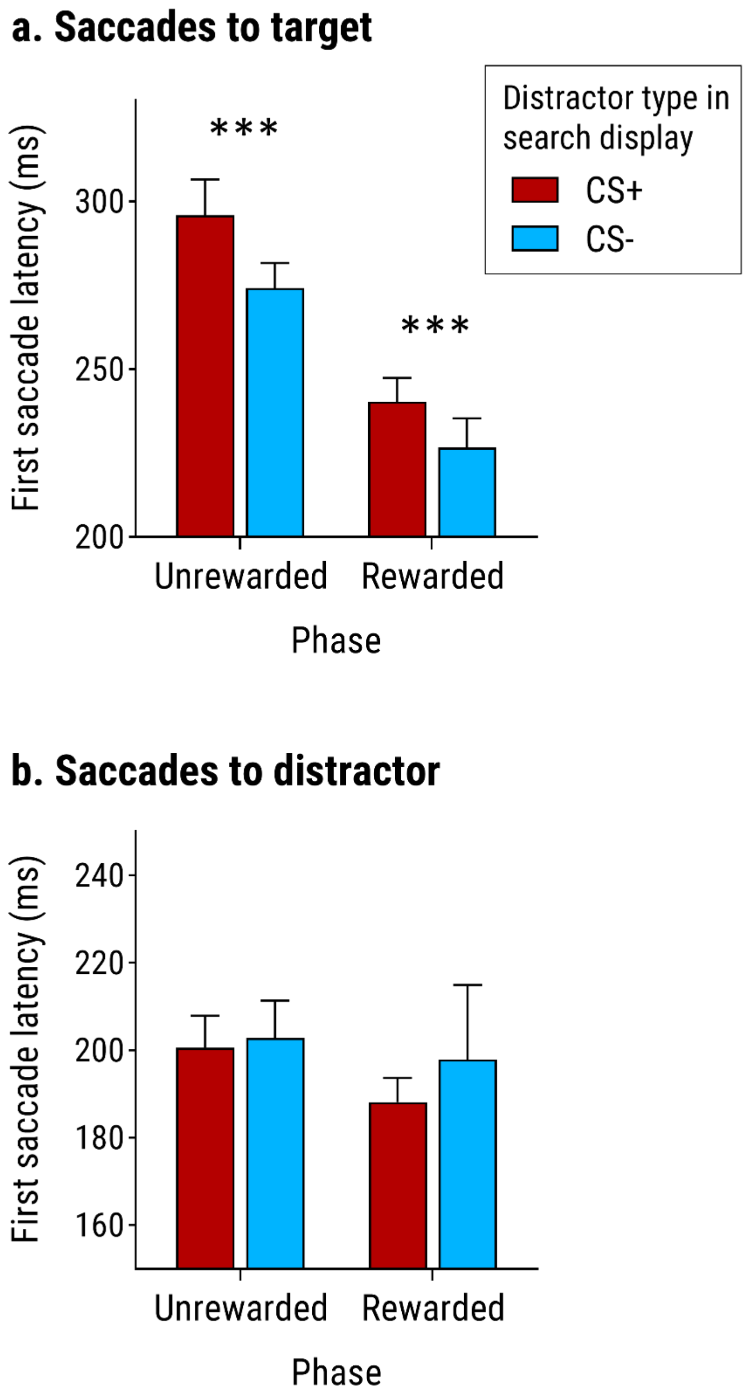

Figure S4. Mean latency of first saccades to **(a)** the diamond target, and **(b)** the coloured distractor in Experiment 2, as a function of whether the display contained a CS+ or CS– distractor, in the Unrewarded and Rewarded phases. Error bars show within-subjects 95% confidence interval (Morey, 2008). *** p < .001.

Gaze Dwell Time

For the subset of trials on which participants looked at the coloured distractor stimulus (CS+ or CS–), we calculated the mean duration for which gaze fell within the region of interest of radius 2.55° visual angle (100 pixels) centred on this distractor. Figure S5 shows the resulting mean gaze dwell time on distractors across phases of Experiment 2 (one participant did not look at the CS– distractor on any trial of the Unrewarded phase, and so was excluded from analysis of dwell time). ANOVA revealed a significant effect of distractor, $F(1,25) = 4.50$, $p = .044$, $\eta_p^2 = .152$, with gaze dwelling for longer on the CS+ than the CS–, and a significant effect of phase, $F(1,25) = 22.3$, $p < .001$, $\eta_p^2 = .471$, with greater dwell on distractors in the (first) Unrewarded phase than the (second) Rewarded phase. The interaction was not significant, $F(1,25) = 0.37$, $p = .551$, $\eta_p^2 = .014$. Pairwise tests revealed that the effect of distractor approached significance in each phase considered separately, both $t(25) = 1.94$, $p = .063$, $d_z = 0.38$.

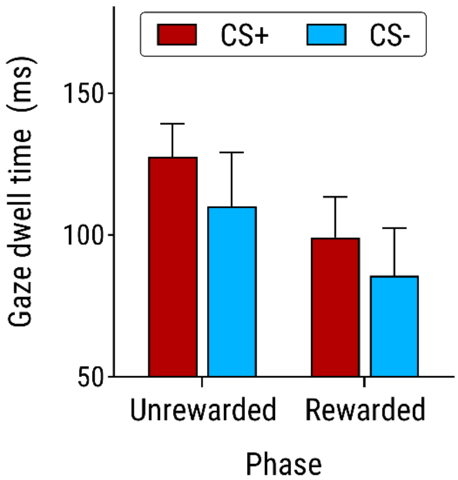

Figure S5. Mean duration of gaze on colour-singleton distractors in Experiment 2, on trials in which participants looked at the distractor, for each distractor condition (CS+ and CS–), in the Unrewarded and Rewarded phases. Error bars show within-subjects 95% confidence interval (Morey, 2008).

We could not analyse dwell times on CS+ trials on Experiment 2 as a function of whether the noise occurred or did not occur (as we did for Experiment 1, see Figure S3) because the noise occurred on *every* CS+ trial of Experiment 2 in which participants looked at the CS+.

General Discussion

In both experiments, latency of first saccades made towards the distractor was considerably shorter than for first saccades towards the target (note different scale in Figures S1A and S1B, and Figures S4A and S4B). This is a commonly observed pattern in studies using the additional singleton procedure (Godijn & Theeuwes, 2002; Le Pelley et al., 2015; Pearson et al., 2015; Pearson et al., 2016) and has been interpreted in terms of *competitive integration* on a saccadic priority map, such that stimulus-driven activity associated with the physically salient distractor inhibits the goal-directed activity associated with the less salient target, such that it takes longer for activity at the target location to reach the threshold for a saccade to be made (Godijn & Theeuwes, 2002; Pearson et al., 2016; see also Sawaki & Luck, 2014).

Of more importance for present purposes were the findings relating to distractor type. In this regard, the patterns for saccade latency (to targets) and dwell time measures in each experiment broadly mirrored those for proportion of distractor-gaze trials reported in the main text. In each case where we observed a significant effect of distractor on the proportion of distractor-gaze trials (namely in the AfterInfo phase for the Full-Info group of Experiment 1, and across both Unrewarded and Rewarded phases of Experiment 2), we also observed a significant effect of distractor type on saccade latency (to targets) and duration of gaze dwell time on the distractor.

With regard to saccade latencies, first saccades made towards the target were delayed when the display contained a CS+ distractor relative to a CS– distractor. An analogous pattern has previously been reported in studies of the effect of reward on oculomotor capture, with slower target-directed saccades when the search display contains a distractor signalling availability of high reward relative to low reward (Le Pelley et al., 2015; Pearson et al., 2015, Experiment 2), though other studies of reward have failed to find a significant effect for this contrast (Pearson et al., 2015, Experiment 1; Pearson et al., 2016; Theeuwes & Belopolsky, 2012). Regardless, the findings of the current study are consistent with the idea that knowledge of the relationship between CS+ and an aversive noise influences the process of competitive integration on the saccadic priority map. One possibility is that the stimulus-driven activity elicited by the CS+ is greater than that elicited by the CS–, thus creating greater inhibition of saccadic activity at the target location, such that it takes longer for the activity peak associated with the target to reach the saccade threshold. It is notable in this regard that neither experiment found significant evidence for an influence of distractor type on latency of saccades made towards the distractor itself – a pattern that has also been consistently found in studies of reward-signalling stimuli (Le Pelley et al., 2015; Pearson et al., 2015; Pearson et al., 2016; Theeuwes & Belopolsky, 2012). If, as suggested above, the CS+ elicited greater stimulus-driven saccadic activity than the CS–, then one might expect to observe faster saccades to the CS+ than the CS–, and yet this was not found. One interpretation of this pattern of results essentially appeals to a floor effect: if stimulus-driven activity elicited by the (physically salient) colour-singleton distractor passes the saccade threshold, it typically does so rapidly such that there is little scope to observe a difference in latencies. It is also notable that the number of trials on which participants made a first saccade towards the distractor was relatively small, limiting the sensitivity of this analysis relative to the analysis of first saccades to the target, which were more frequent (e.g., summing across phases and distractor types in Experiment 2, participants had a mean of 248 trials on which the first saccade went to the target, and only 104 on which it went to the distractor).

We also found an influence of distractor type on the duration for which gaze dwelled on the distractor (evaluated on the subset of trials on which participants looked at the distractor). Specifically, gaze remained on the CS+ for significantly longer than on the CS–. One possible interpretation of this finding is that, once attention and gaze had been captured by the distractor, the CS+ held attention for longer: that is, participants were slower to disengage attention from a stimulus known to be associated with an aversive outcome. However, deeper analysis of the data from Experiment 1 indicated that the pattern of greater dwell time on CS+ trials reflected a disruptive influence of the noise itself, rather than being a consequence of learning about the threat-signalling status of the CS+. Specifically, the pattern of significantly greater dwell on the CS+ than the CS– was observed only for CS+ trials on which the noise was delivered, and not for trials on which the noise did not occur (corresponding analysis was not possible for Experiment 2, since the noise occurred on all CS+ distractor-gaze trials in this experiment).

Our nonsignificant (in Experiment 1) and confounded (in Experiment 2) findings in this regard do not rule out the idea that learning about the threat-signalling status of a stimulus might influence the ease of attentional disengagement from that stimulus. Our procedure was not designed to investigate this possibility and was not optimal for doing so: as noted above, there were relatively few trials on which participants looked at the distractor, limiting power to detect differences in dwell time – and in Experiment 2 we could not deconfound effects of learning about the CS+ and unconditioned effects of the noise on dwell time.

Future studies could investigate the possibility of effects on attentional disengagement using better-tailored designs, for example based on the approach used by Watson, Pearson, Theeuwes, et al. (2020) in the context of reward-signalling stimuli. The idea that threat-related distractors might hold attention is consistent with results of previous studies that have been taken as demonstrating delayed disengagement of attention from threat-related stimuli (e.g., Fox et al., 2002; Mogg et al., 2008). However, these previous studies have used variants of the dot probe procedure (MacLeod et al., 1986) in which a target probe was equally likely to appear at the location of threat-related versus neutral information, and hence (unlike in the current procedure) attentional bias to threat-related stimuli was not counterproductive. As such, patterns of attention in those prior studies may have been entirely goal-directed: participants may have chosen to look at the threat-related stimuli for longer because they were more interesting, and there was no disadvantage to doing so (see Watson, Pearson, Theeuwes, et al., 2020, for further discussion of this issue). By contrast, the current study examined attention to threat-related stimuli under conditions in which attending to these stimuli was entirely counterproductive (and participants were aware of this). Future research could examine whether threat influences disengagement under these more stringent conditions, investigating whether threat has an automatic effect, making it harder for participants to disengage attention even when they are motivated to do so. Such a finding would parallel findings that have been observed in the context of reward (Watson, Pearson, Theeuwes, et al., 2020), where it has been shown that participants are slower to disengage attention from stimuli that signal availability of high reward versus low reward, even when attending to these stimuli is counterproductive.

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